CENTER FOR LUNAR SCIENCE AND EXPLORATION

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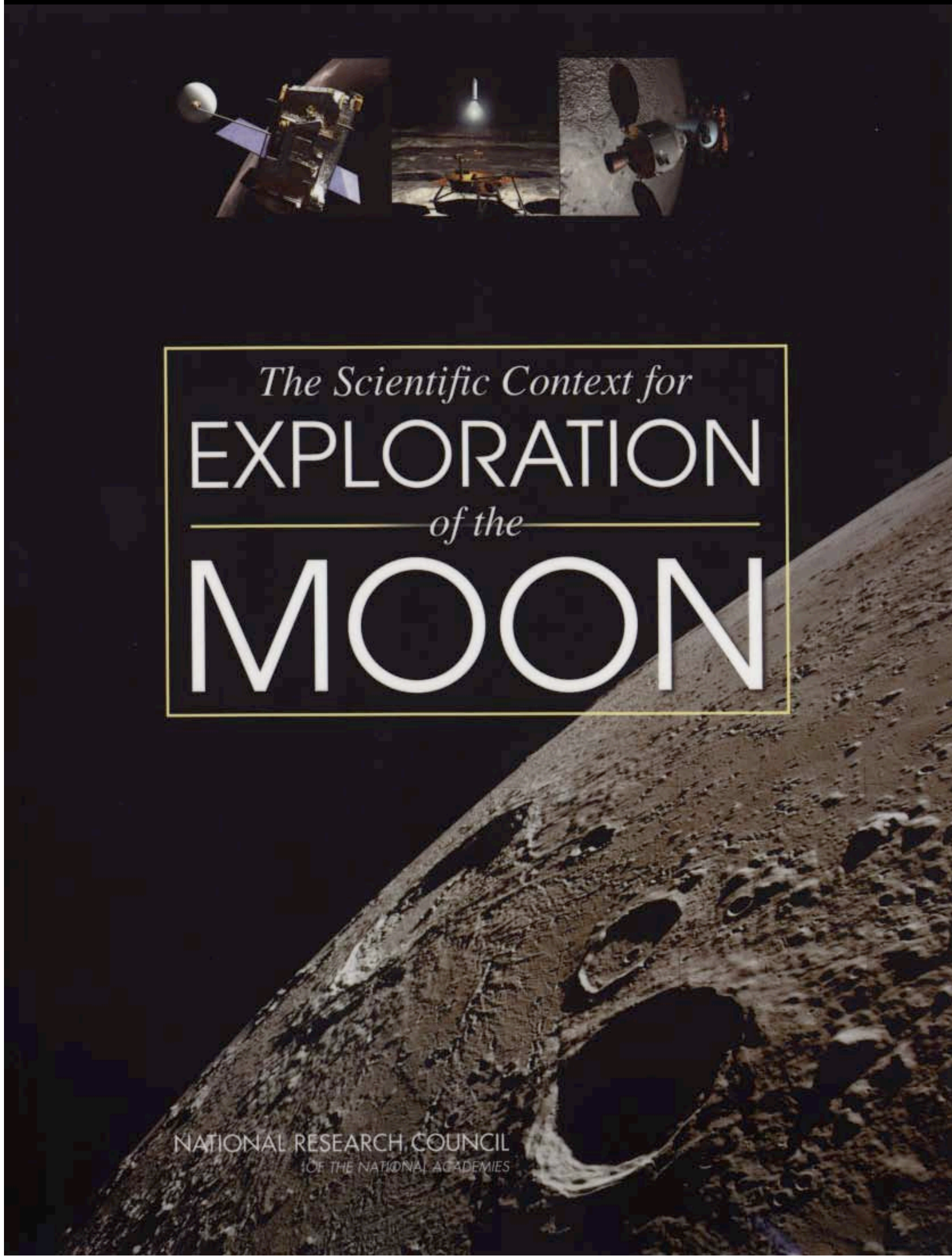
Lunar and Planetary Institute · NASA Johnson Space Center Astromaterials Research & Exploration Science · USRA · Rice · The University of Arizona · University of Houston · University of Maryland · University of Notre Dame

Mission Design and Astronaut Training Needed to Determine the Impact Flux on the Moon and throughout the Inner Solar System

David A. Kring



Number one science concept & highest science priorities

1. The bombardment history of the inner solar system is uniquely revealed on the Moon
   - a. Test the cataclysm hypothesis by determining the spacing in time of the creation of lunar basins
   - b. Anchor the early Earth-Moon impact flux curve by determining the age of the oldest lunar basin (South Pole-Aitken Basin)
   - c. Establish a precise absolute chronology
   - d. Assess the recent impact flux
   - e. Study the role of secondary impact craters on crater counts

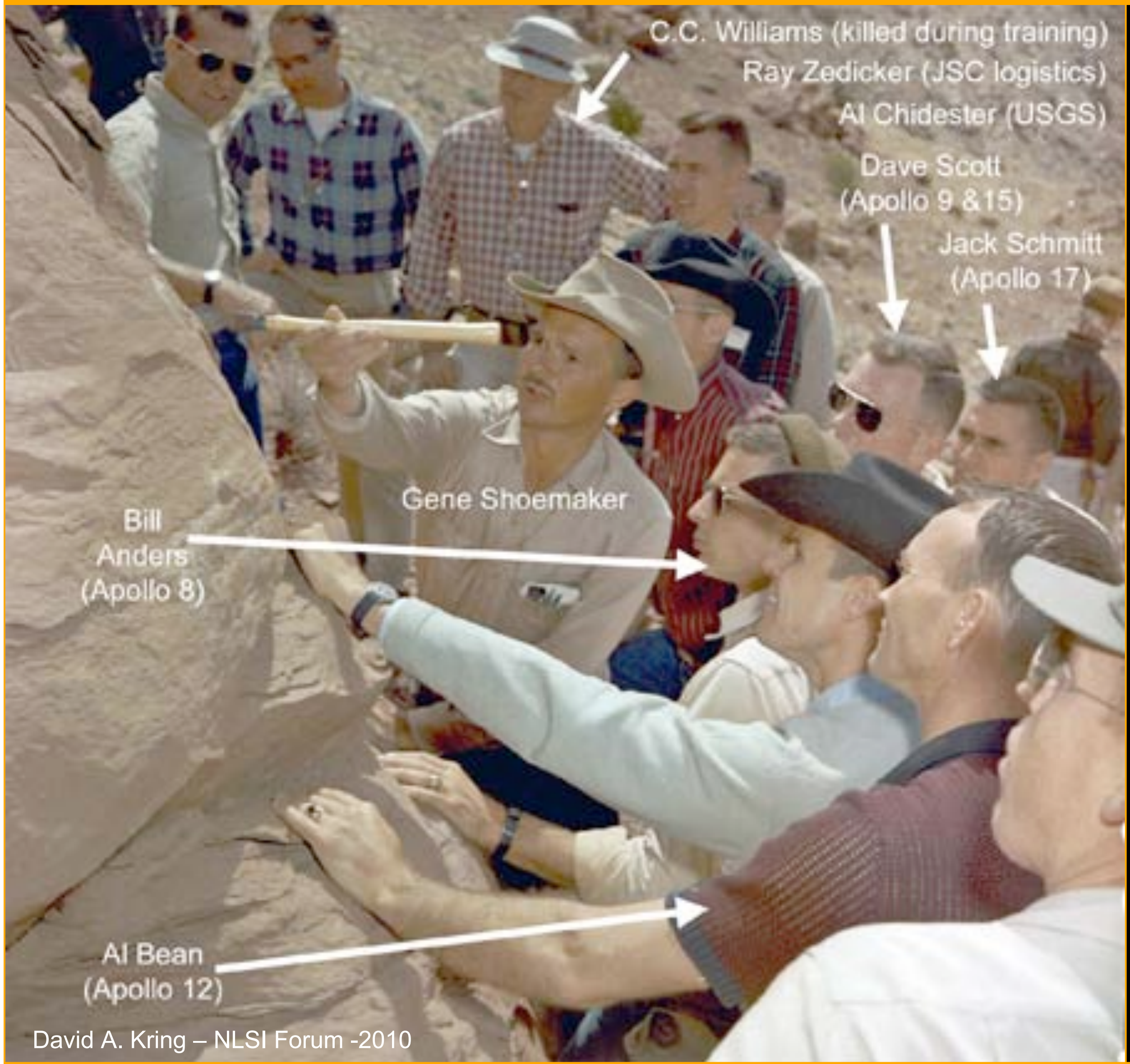
To complete those tasks, crew need to learn about

- Crater morphology,
- Associated structural elements,
- The distribution of impact lithologies, and
- How to locate samples suitable for determining the ages of craters

Crew also need to learn that

- Complex craters and multi-ring basins are excellent probes of the crust & lunar interior, and
- How to utilize those probes to locate suitable samples for return to Earth


Barringer Meteorite Crater, Arizona
(*aka* Meteor Crater)



In-field Classroom

(Show, tell, & discuss)

- Examine uplifted & exposed units
- Examine overturned units
- Examine different types of breccias associated with an impact crater

Field Exercises

(Hands-on & engaged learning requiring critical real-time analyses)

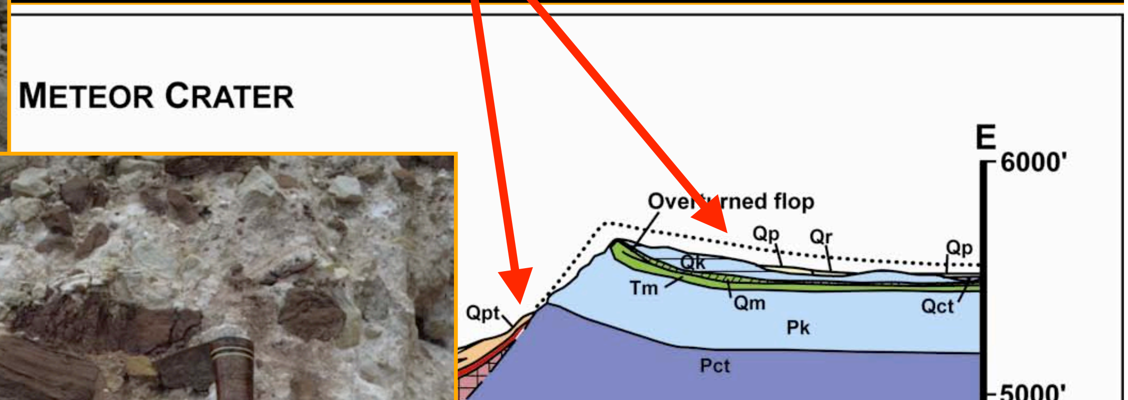
• Measure deformation caused by an impact event

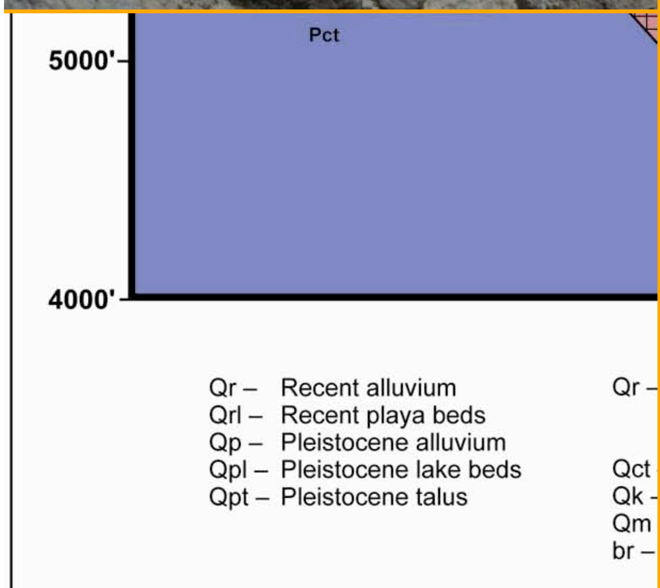
• Locate excavated lithologies in the ejecta blanket

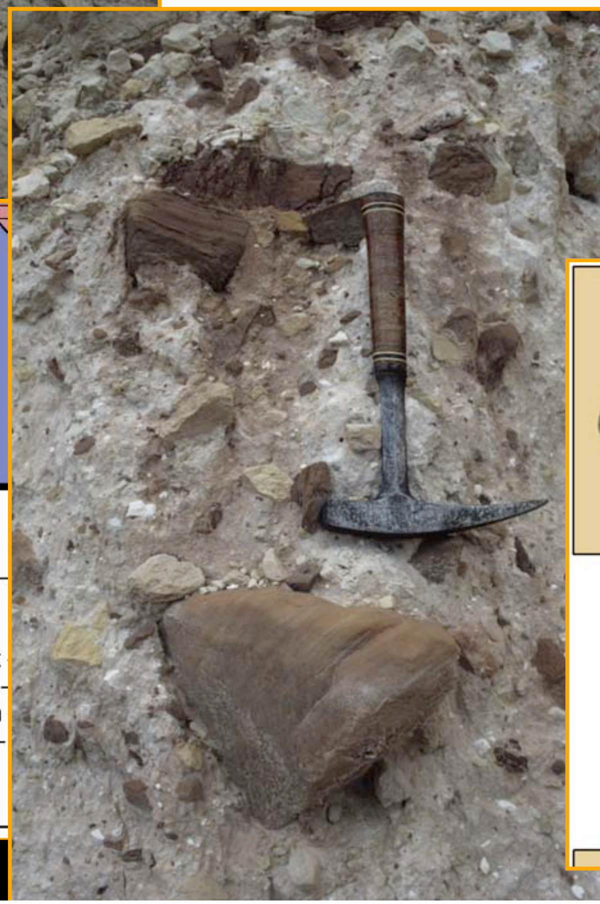
• Locate impact melt

• Traverse exercises (a) across the crater floor to a crater wall and (b) across ejecta blanket towards the crater rim

Distribution of impact breccias & impact melts







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Schooner Crater, Nevada

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South Ray Crater (Apollo 16)

- Oblique "aerial" view from *Orion* (LM)
- Uplifted rim with ejecta blanket
- 680 m diameter crater

Apollo 16, Station 8
Boulder C
One of several boulders in ejecta blanket
of South Ray Crater
Collected in hopes of determining age of crater

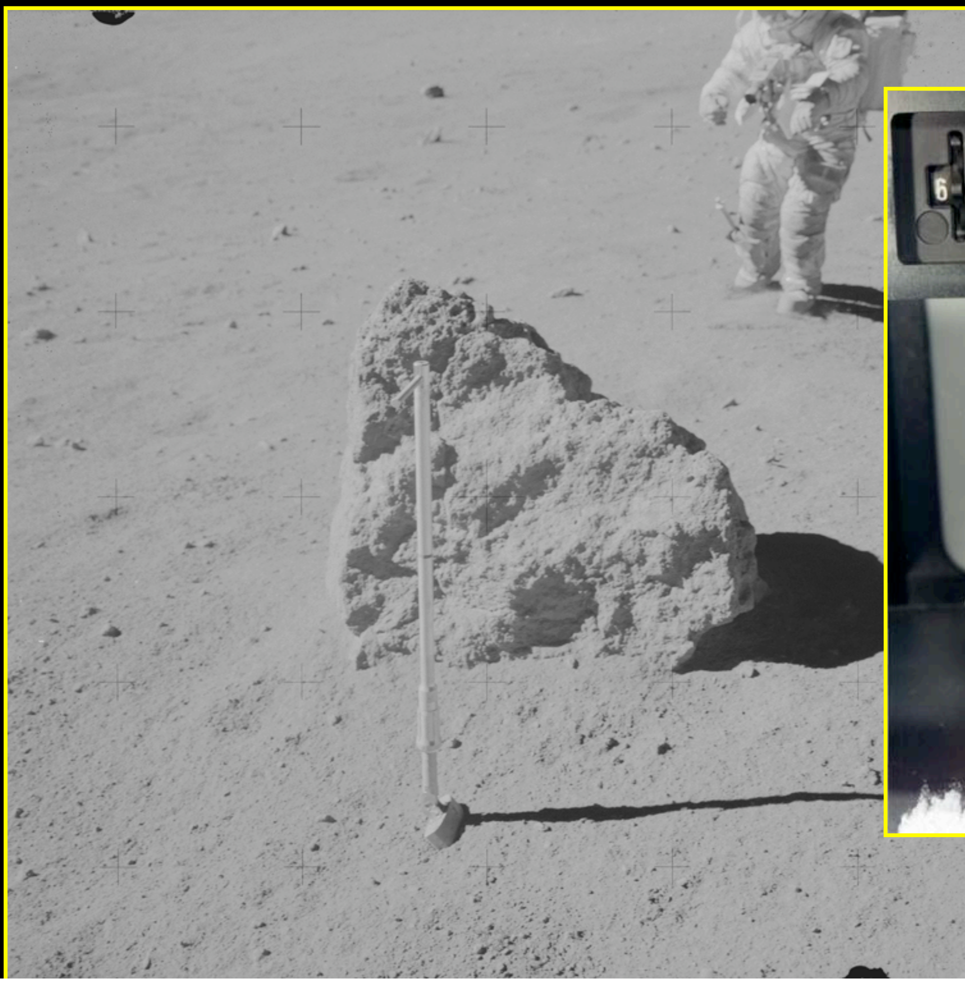
Apollo 16, Station 8
Boulder C
One of several boulders in ejecta blanket
of South Ray Crater
Collected in hopes of determining age of crater → We now know that this was a fruitless exercise.

Such a small crater was not going to produce such large blocks of melt with representative ages and eject them to such far distances.

Samples of impact melt in these localities were produced by older impact events & excavated by the South Ray event.

Thus, the sample has an age that is older than that of the South Ray Crater event.

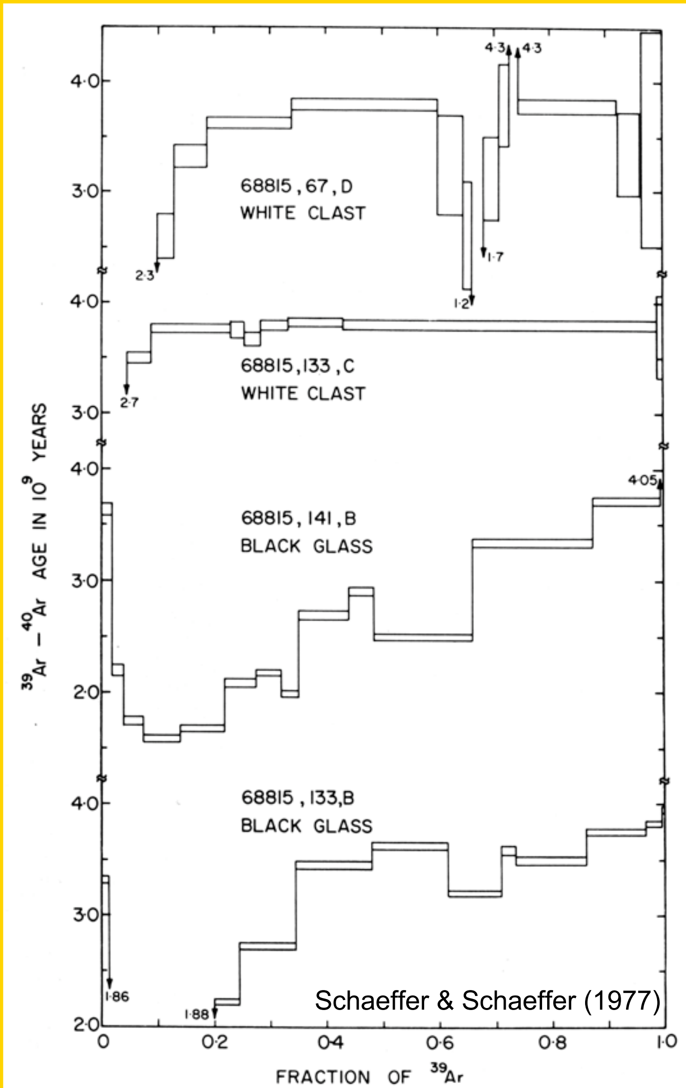
Apollo 16, Station 8
Boulder C
One of several boulders in ejecta blanket
of South Ray Crater
Collected in hopes of determining age of crater



68815

In thin-section, the sample has
multiple flow structures and glass

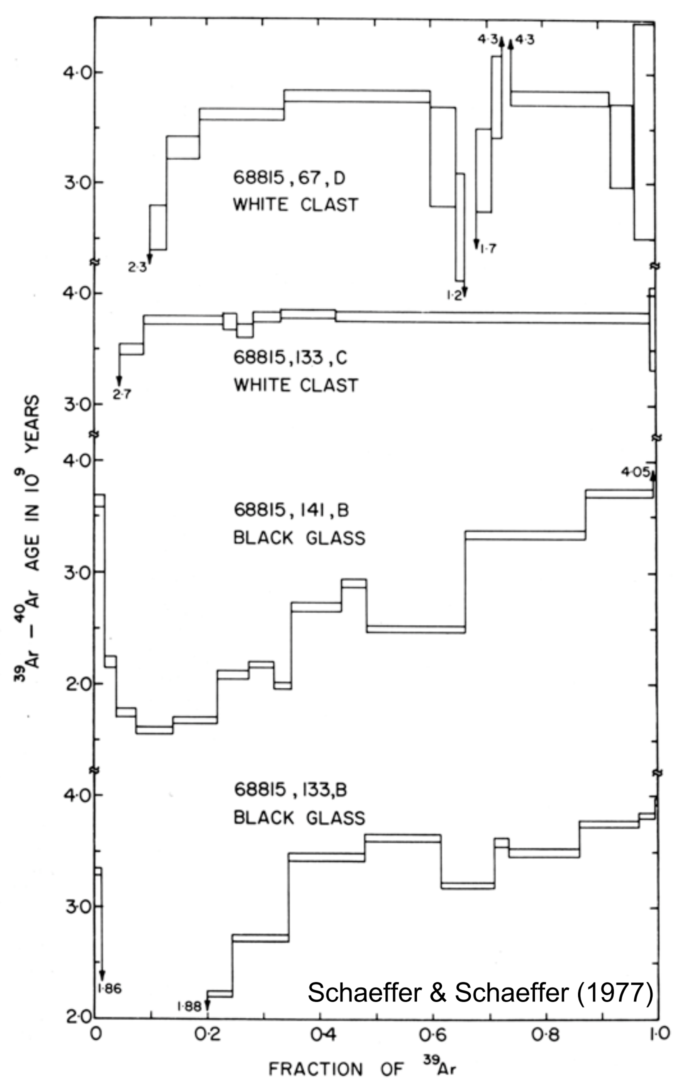
Glassy Melt Breccia 68815



A 3.81 Ga age was inferred for these two clasts

A 3.76 Ga age was inferred for these two splits of melt

Glassy Melt Breccia 68815



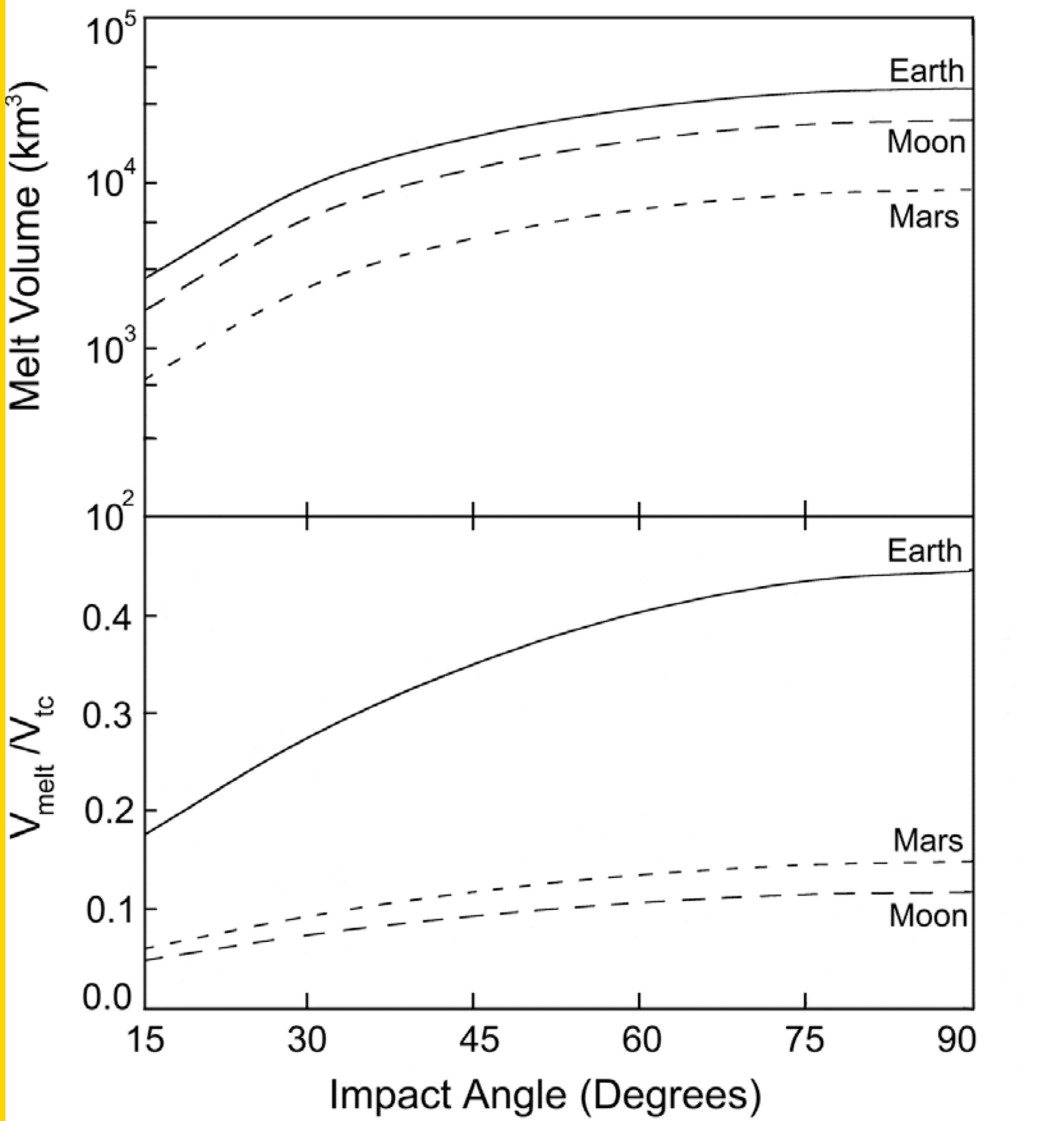
A 3.81 Ga age was inferred for these two clasts

A 3.76 Ga age was inferred for these two splits of melt

The 3.7-3.8 Ga age is too old to represent South Ray Crater; rather, 68815 is an older impact lithology that was excavated by the South Ray Crater event.

Some Lessons Learned from Apollo

- Impact events do not “shock” reset the ages of ejected debris. Samples can be ejected and/or shock-metamorphosed, but may not necessarily have reset ages.
- Impact melt or impact melt breccias need to be heated to sufficiently high temperatures for sufficiently long time for degassing to reset radiometric clocks.
- Impact melt breccias are complex lithologies that must be subdivided (at a minimum into clast and melt fractions) to obtain reliable ages.



Lunar Impact Melt Volume

- Previously, melt volumes for lunar craters assumed vertical impacts (which could be modeled with 2D hydrocodes)

- We have derived a method for calculating impact melt volumes for impacts of any trajectory and scaled appropriately for each of the terrestrial planetary surfaces (which is fully consistent with new 3D hydrocode models of impact cratering processes)

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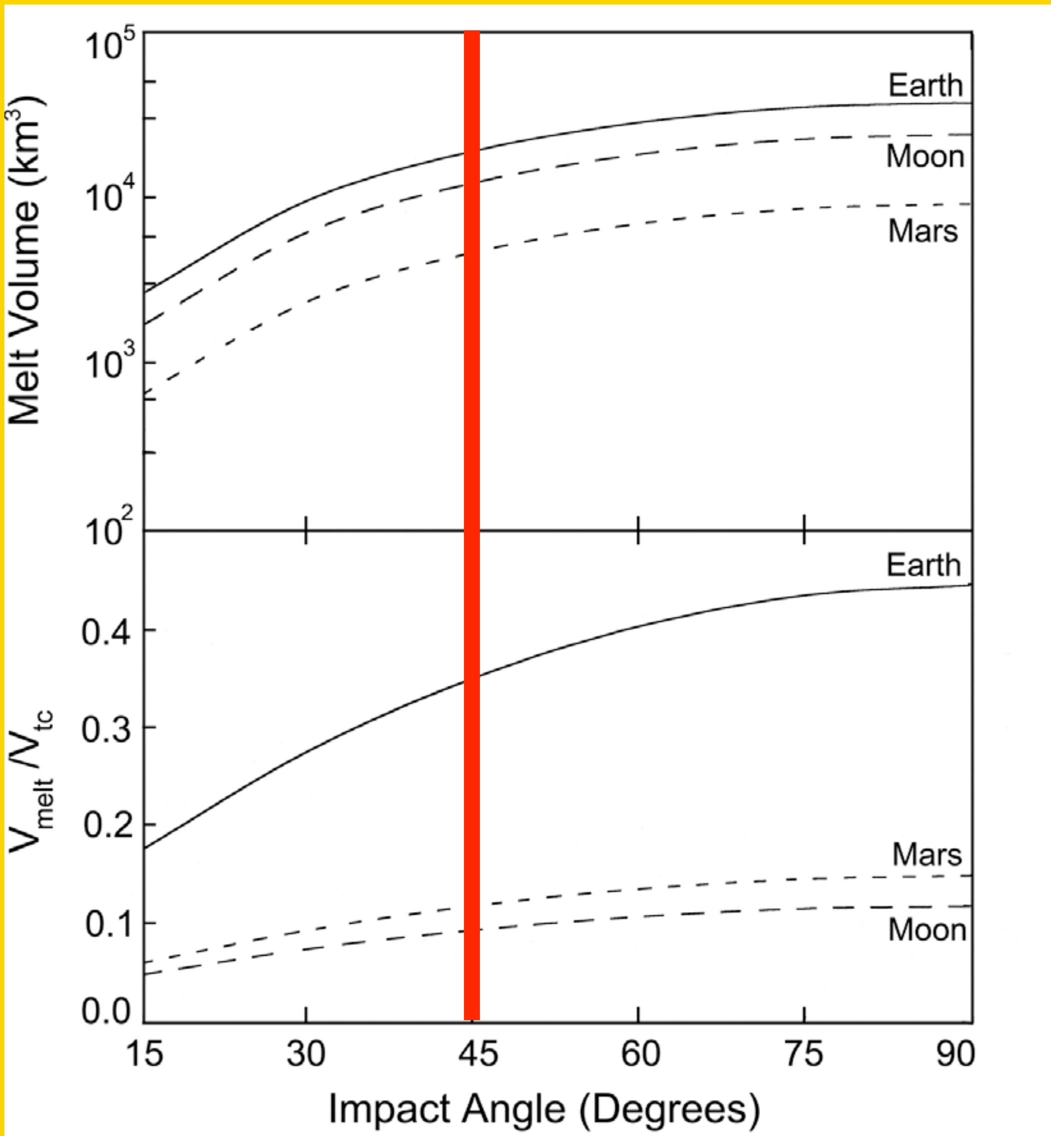

Lunar Impact Melt Volume

- Melt volume for the most probable impact angle (45°) is less than that previously calculated assuming vertical impacts.

- Melt volume for an impact on the Moon is less than that for a similar impact on Earth.

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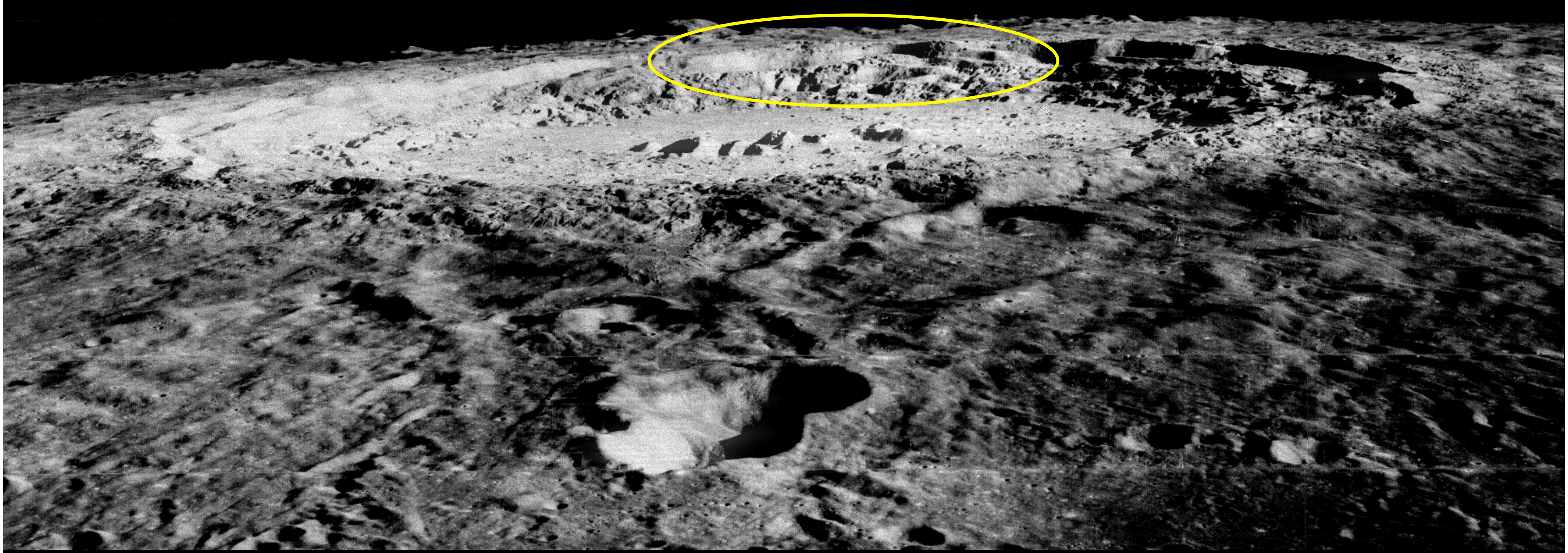
Lunar Impact Melt Volume

- For the most probable impact angle (45 degrees), 2 times less melt volume is produced than in a vertical impact (and over 7 times more melt volume than a very oblique (15 degree) impact)
- For a similar size transient crater diameter, a lunar impact produces less melt than a terrestrial impact
- In terms of final crater diameters, there is more melt in the Chicxulub crater on Earth (~180 km) than the similarly-sized Tsiolkovskiy crater (~180 km) on the Moon
- Collectively, these results imply thinner central melt sheets and a smaller proportion of melt particles in impact breccias on the Moon (and Mars) than on Earth.

Sampling Lunar Impact Melt

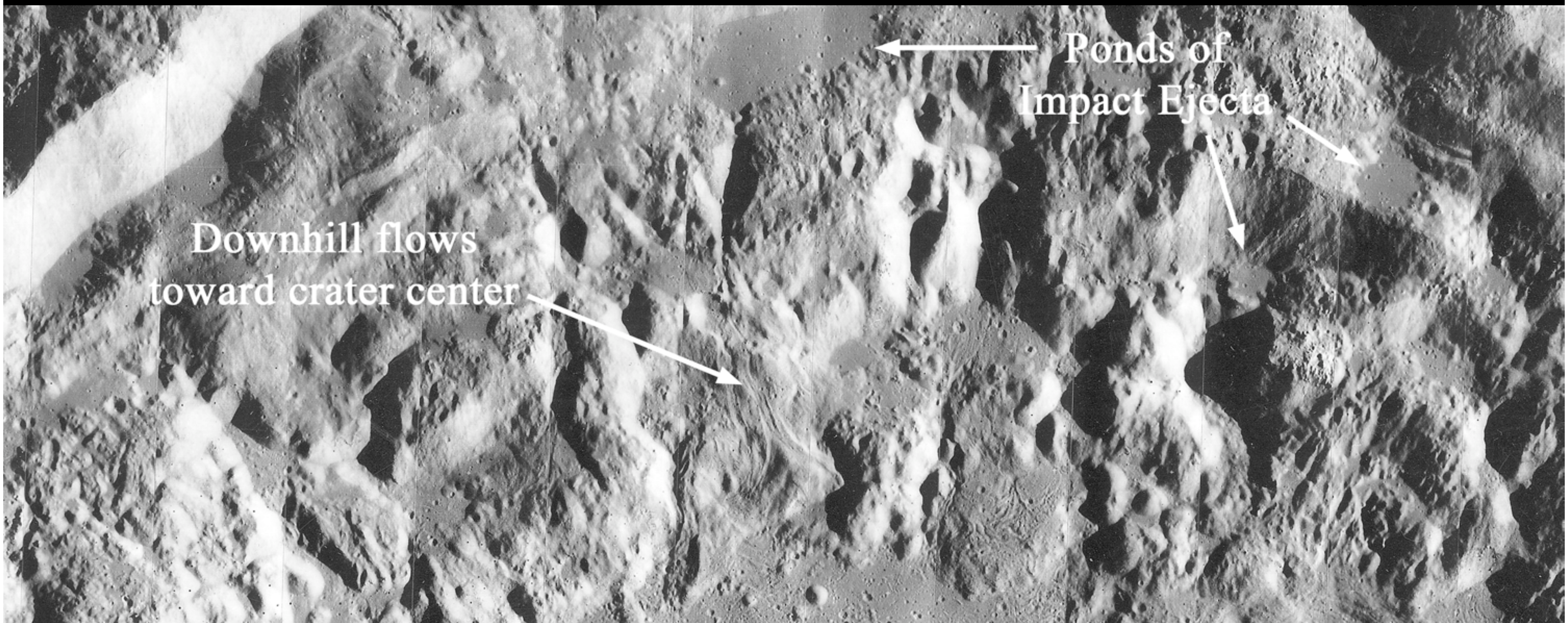
Copernicus Crater



~93 km diameter, 3.8 km deep

Lunar Orbiter II

Sampling Lunar Impact Melt

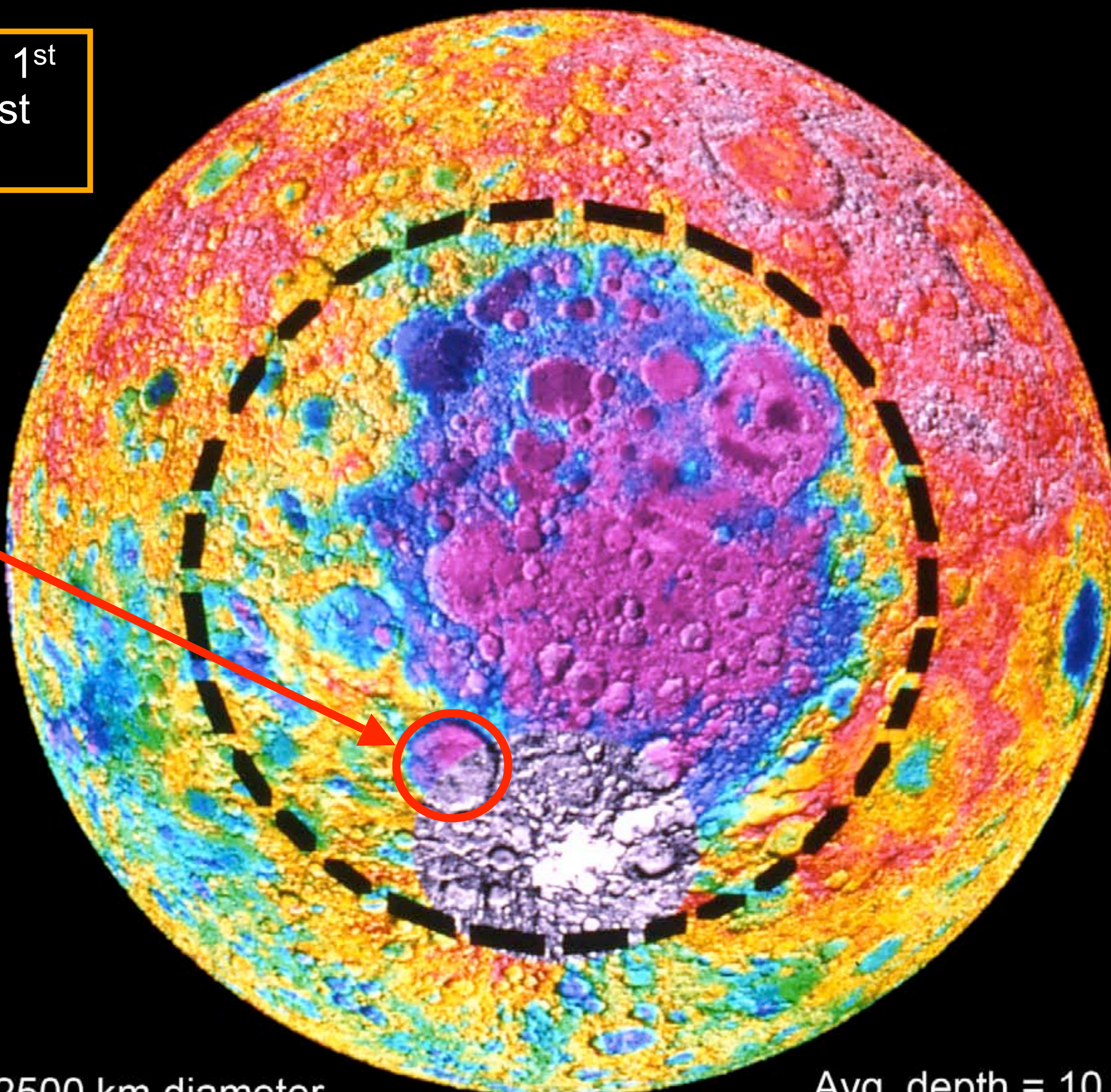


Lunar Orbiter V

- Impact melts can be collected within lunar craters
- Alternatively, they can be collected from debris ejected from impact craters

South Pole-Aitken Basin

Addressing the 1st and 2nd highest priorities

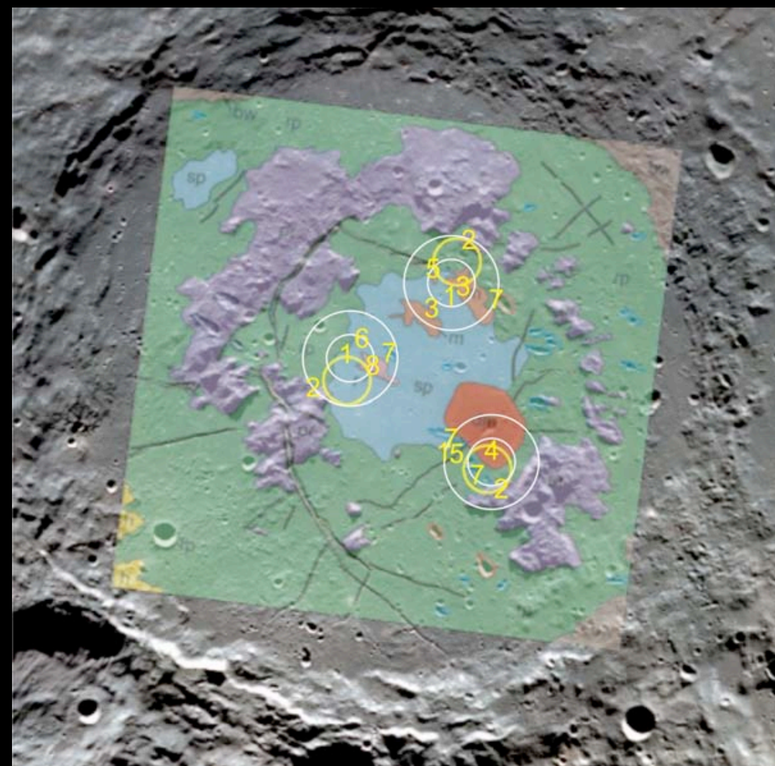


Schrödinger Basin (~320 km Diameter)

~2500 km diameter (LPI)

Avg. depth = 10 km
Max. depth = 13 km

Schrödinger Basin
within South Pole-Aitken Basin



Kohout et al. (2009); O’Sullivan et al. (2009)

This single target can virtually bracket the entire basin-forming epoch

EV2 of Crew B removing tool and sample carriage or stand from geologic tool rack at the Black Point Lava Flow test site (2008).

EV2 is conducting a single person EVA; EV1 is conducting IVA from within the LER.

Geologic Tool Rack

- Hammers
- Tongs
- Scoop
- Sample bags
- Sample storage compartment

- Augmented with LER tools (e.g., for cleaning windows)

EV1 and EV2 workt together at Station 2 of a traverse at the Black Point Lava Flow test site (2008). Crew are vocalizing a description of the sample and photo-documenting the outcrop prior to sample collection.

Sample Recovery

- Locating appropriate outcrop based on pre-traverse briefing and real-time discussion with the Science Operations Room
- Describing outcrop to Science Operations Room
- Photodocumenting the outcrop and its geologic context
- Removing sample(s)
- Re-photodocumenting the outcrop to confirm sample location

Sample Documentation

- Each suit has a camera that streams images
- To be recorded on the LER
- Or captured in the Science Operations Room

EV2 of Crew B documenting a basalt sample collected on the N1 Traverse at the Black Point Lava Flow test site (2009). While a sample image is collected, EV2 is vocalizing a description of the sample.

A single station within the Science Operations Room was assigned to capture images and record sample descriptions from both EV1 and EV2.

Lunar mission simulation program

At the Black Point Lava Flow

- Multiple 1- and 3-day missions with unpressurized and pressurized rovers and crew (2008)
- 14-day mission with pressurized Lunar Electric Rover (LER) and crew (2009)

At the expanded Black Point – Colton Crater Site

- 14-day mission with 2 LER, crew, other hardware assets and variable communication capabilities (2010) – tests operational concepts to be utilized in 28-day mission to the Malapert Massif at the margin of SPA Basin

Provides an opportunity to test operational strategies that involve crew, mission ops staff, and science ops staff, which has greatly enhanced science productivity.

Astronauts involved in lunar mission simulations

Geologic traverse and station activities

- Mike Gernhardt & Rex Walheim (BPLF 2008)
- Mike Gernhardt & Andy Feustel (BPLF 2009)
- Mike Gernhardt, Stan Love, Stephanie Wilson (BPLF, SP Crater, & Colton Crater 2010)

Upcoming astronaut training activities

Lunar regolith processes – August 2010

- New class of astronauts
  - Roy Christofferson & Dave Carrier
  - JSC Lunar Curatorial Facilities

Impact cratering processes – January 2011

- New class of astronauts
  - Fred Hörz & David Kring
  - LPI and JSC

Impact cratering processes – Spring 2011

- New class of astronauts
  - David Kring
  - Meteor Crater

Serena Aunon – NASA
Jeanette Epps – NASA
Jack Fischer – NASA
Michael Hopkins – NASA
Kjell Lindgren – NASA
Kathleen Rubins – NASA
Scott Tingle – NASA
Mark Vande Hei – NASA
Gregory Hiseman – NASA
Jeremy Hansen – CSA
Norishige Kanai – JAXA
Takuya Onishi – JAXA
David Saint-Jacques – CSA
Kimiya Yui – JAXA

Thank you.